increasing interest in investigations of safety problems peculiar to the industries of each state. Their function has been to investigate fundamental problems relating to the efficient use of the material resources of the state, but the change of emphasis brought about by the safety movement will make safety problems of equal moment.

Another agency for the organized study of safety problems is found in the banded casualty insurance companies, who are in a peculiarly favorable position to bring an economic pressure to bear upon the industries to install standard, adequate safety devices. They propose to offer a reduction in rates where approved safety devices are installed and the underwriters' laboratories are hereafter to test approved safety devices to reduce accident risks as well as devices for reducing fire risks.

The general government is also aiding in safety engineering, as it is the province and duty of the Federal Bureau of Mines to conduct investigations with a view to increasing safety in the mining, quarrying, metallurgical and other mineral industries. This is the first government bureau to be established with the specific object of studying industrial safety in fields other than transportation. The laboratory facilities include an equipped coal mine for the study of mine explosions, chemical and physical laboratories, and the new buildings about to be commenced include mechanical and electrical laboratories.

These numerous agencies for the careful study of safety problems, which lie just behind the field of the self-evident and in the land of the more or less obscure, will each contribute something to the motley interests of the safety engineer and will help to eliminate industrial accidents.

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ISOSTASY AND RADIOACTIVITY[1]

IT is the purpose of this paper to point out some apparent discrepancies between the observations of geodesists on isostasy and the inferences which some radiologists have drawn as to the great age of certain specimens of minerals. It seems well to begin by reviewing the results of isostatic investigations in order to estimate the degree of confidence to which they are entitled; and recent advances in radiology demand similar attention.

Correlation of these widely distinct researches is possible because it happens that the emission of heat by a globe whose excess temperature is due solely to radioactivity obeys Fourier's law exactly as does that emitted by a hot but radioinactive globe.

Geology as a science is conditioned by the state of the earth's interior, and our knowledge of its constitution is now advancing. So late as the foundation of this society in 1889 the Cartesian doctrine of a fluid earth enclosed in a very rigid shell a score or two of miles in thickness was held by most geologists. We now know that the globe is solid and on the whole of great rigidity and probably divisible into at least four distinct shells each more rigid than that overlying it, that the irregularities in density and structure which are so marked at the surface extend only to a depth of something like a fiftieth of the earth's radius; that open cavities or cracks may exist at depths of 20 miles and very possibly down to the level of isostatic compensation. We know too that the earth is radioactive but that the radioactivity is superficial, reaching only to a moderate though uncertain level; we also know, however, that the earth's heat is not wholly

[1] Abstract of the presidential address before the Geological Society of America, December, 1914. The full paper is too long for oral delivery and only this abstract was read at the meeting.

of radioactive origin. More information is certainly in store for us, for Mr. Michelson is now measuring the terrestrial tides in terms of the wave-length of light, while methods have been developed by which the distribution of density above the level of isostatic compensation can be studied.

Thus the future is full of hope. The rational method of attaining it is to make trial hypotheses, and to devise methods of testing them.

Laplace seems to have been the first to grasp the problem of isostasy and in 1818 he maintained that the irregularities of the earth and the causes which disturb its surface extend to but a small depth. I do not find in his memoirs any rigorous proof of this interesting anticipation. Sir John Herschel in 1833 regarded the earth as a yielding mass and considered erosion and deposition as the primum mobile of geology, but he did not pursue the subject. Archdeacon Pratt in 1858 first expressed the hypothesis of isostasy in exact terms, discussing it mathematically and adducing evidence in its favor from the geodetic survey of India.

As we all know, the enormous labor needful to prove the hypothesis from deflections of the vertical was undertaken by Mr. John F. Hayford. Mr. Helmert characterized Hayford's investigation as "truly magnificent" and called the underlying idea the Pratt-Hayford hypothesis.

Helmert himself devised a method of testing isostasy by observations on the intensity of gravity instead of deflections. His results coincide almost exactly with Hayford's and thus immensely strengthen the theory. At Helmert's suggestion also Mr. O. Hecker made many observations on the intensity of gravity at sea. These observations are indeed of inferior accuracy, but suffice to prove that isostatic compensation exists beneath the Atlantic and the Pacific as well as under the United States.

In my opinion the geodetic evidence for isostasy is so manifold and so consistent as to amount to proof. Equilibrium is nearly or quite complete at a depth of between 110 and 140 kilometers, the most probable value being near 120 kilometers.

Messrs. Hayford and Bowie have also investigated the effect of isostasy on the intensity of gravity in the United States and at selected stations in other parts of the world. This research confirms the existence of isostasy, but reveals certain anomalies due either to imperfect compensation some 120 kilometers from the surface or to irregularities in the distribution of density, or to both causes.

It is shown in my paper that the largest deflections in the United States and also the largest anomalies could be accounted for by a spherical batholith, say of peridotite, just buried beneath the surface and having a diameter of 8½ miles. Of course such a batholith would not be considered surprising by geologists. When the existence and abundance of dikes, sills and laccoliths at all accessible levels is considered, as well as the probability of their prevalence at all levels above the deepest volcanic foci, it appears that heterogeneities in the earth's outer shell are of the order of magnitude needful to account for the gravity anomalies. In short there is much evidence for the conclusion that compensation at the compensation level is very nearly complete.

If so, the mass beneath that level must be almost free from strain and can have cooled but little from its primeval temperature.

On the isostatic theory the continents stand out above the bottom of the ocean because of inferior density. This inferiority may be due to higher temperature or to voids such as joints, or to both. A third possibility is that it might be due to lithological differences, but of that there is no

evidence. The sub-continental temperature is comparatively high; for the thermometric gradient shows that at the level of average sea bottom the rocks below the continents have a temperature of about 100°, while at the bottom of the sea the thermometer stands near zero. As for crushing and jointing, recent experiments in my laboratory show that the volume of a brittle substance such as sulphur, confined in a brass tube, may be increased to the extent of more than six per cent. by bending the tube. There can be no question that rocks would behave in much the same way under such confinement as that to which deep-seated rocks are subject.

If the average subcontinental mass down to the compensation level had 3 per cent. more voids than the sub-oceanic mass, this would account for the present mean elevation of the land. The same result would follow if the average temperature under the continents were 40° higher than under the ocean. Or again, the combination of 20° excess of temperature and $1\frac{1}{2}$ per cent. excess of voids would account for the continents.

If the areas occupied by the continents were originally bounded by the same level surface as the ocean bottoms, but possessed a smaller conductivity, so that they cooled more slowly, then it can be shown that the earth would constitute an imperfect heat engine and that abundant energy would be available for crumpling and crushing of the rocks or for the elevation of the continents.

Passing now to the recent developments of radiology, that wonderful branch of physics has very recently developed fresh surprises. Rutherford has put forward a nuclear theory of the atom, and van den Broek has shown that the place of an element in the periodic table is determined not by its atomic weight, but by the number of positive electric charges carried by the nucleus. This number of charges is known as the atomic number.

Now comes the astounding feature of the subject. It has been definitely discovered by Mr. Soddy, Sir Ernest Rutherford and others that a single atomic number may be borne by each of several substances which may have different atomic weights and, in the case of radioactive substances, different stabilities, but which are inseparable by ordinary chemical or physical properties. They display the same chemical reactions, the same electrochemical behavior, the same spectrum, the same volatility. It would appear, according to Rutherford, that the charge on the nucleus is the fundamental constant which determines the physical and chemical properties of the atom. Soddy calls the members of a group of elements bearing a single atomic number and occupying therefore a single place in the periodic table "isotopes."

So far as lead is concerned, this revolutionary doctrine has been authoritatively confirmed by T. W. Richards, who actually finds the atomic weight of lead from uraninite deposits unmistakably lower than that of ordinary lead.

The discovery of isotopism sufficiently explains the great discrepancies in the ages of minerals as computed from the uranium-helium ratio and the uranium-lead ratio. These ratios also no longer seem adapted to age determinations. It seems very possible, however, that the growing knowledge of atomic structure may eventually lead to trustworthy methods of age determination from radioactive phenomena; but in the meantime other methods must be resorted to.

If the earth has cooled externally from a high temperature, there must be a certain level at which the temperature of the rock most closely approaches the melting point at the prevailing pressure. This may

be called the eutectic level because the additional temperature necessary to fusion would there be a minimum. The question then arises what relation may be supposed to exist between the eutectic level and the level of compensation.

In computing the temperature distribution of a cooling globe which owes a part of its heat to compression, or to initial temperature, and another part to radioactivity, it is necessary to proceed by trial and error, or to test various assumptions and consider which best fits the facts. I have assumed various ages and computed other conditions corresponding to the actual heat emission of the globe. These other conditions are the depth of the eutectic level, the thickness of the radioactive shell (supposed uniform) and the proportion of the surface gradient due to radioactivity. Two cases are of special interest, the assumed ages being 68 million years and 1,314 million years.

For the lower age the eutectic level is at a depth of 121 kilometers, and thus coincides with Hayford's compensation level, the radioactive layer is 2.58 kilometers thick and radioactivity supplies 1/7 of the surface gradient or of the earth's heat emission. For an earth 1,314 million years old the eutectic level lies at 300 kilometers, the radioactive layer is 12 kilometers thick and just 2/3 of the surface gradient is due to radioactivity. In this ancient earth the highest temperature excess due to radioactivity would be found at and below the bottom of the active layer and would amount to only 106°. This is not much in comparison with the temperature of lavas and, if this age is the highest worth considering, most of the earth's heat must be due to compression.

So great an age as 1,314 million years seems incompatible with other features of the problem. This age implies that a thick shell extending from the compensation level downward to and beyond the eutectic level, a shell more than 200 kilometers in thickness, has cooled after solidification through an average temperature interval of about 600°. Now the geodesists have shown that at the compensation level the strains must be small, and I have given reason for believing these strains even smaller than those computed by the geodesists. But I hold it impossible that a layer of rock 200 kilometers thick can cool 600° without setting up large strains.

On the other hand, no such difficulty arises in the case of an earth 68 million years old, for it is easy to show that only a very small amount of cooling has occurred below its eutectic level. Furthermore, in this case the level of compensation acquires a definite and intelligible physical interpretation. Local fusion would bring about compensation. Where, then, should we look for compensation if not at the eutectic level?

In such speculations as this some latitude must be allowed. If, as the geodesists suspect it may be, the compensation level is as deep as 140 kilometers, and if this is also the eutectic level, the earth is 100 million years old, the radioactive layer is 4.74 kilometers thick and 26 per cent. of the heat emitted by the earth is of radioactive origin.

It has often been asserted that the discovery of radioactivity indefinitely prolongs the probable age of the earth. To me it seems that the determination of the level of compensation limits both the age of the earth and the amount of radioactive matter in its outer shell.

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THE CONSTITUTION OF THE ATOM[1]

The subject of the constitution of the atom has come into extreme prominence—great ad-

[1] From the address of the president of the Royal Society, Sir William Crookes, at the anniversary meeting on November 30, and printed in *Nature*.